Magnetic Storms of March 7–8 *and August* 15–16, 1918, *and their Discussion.*

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§1. A recent paper* described the records obtained at Kew and Eskdalemuir Observatories of a world-wide magnetic storm which occurred on December 16–17, 1917. The outstanding feature was the much larger size of the disturbance at the more northern station. This seems a general fact, of which the two magnetic storms discussed in the present paper afford further evidence. They were two of the principal storms of 1918. Their joint discussion affords an opportunity of emphasising the variety in the phenomena exhibited by storms of the same class. The results differ so much from some which Dr. S. Chapman† has given in a recent paper as representative of world-wide magnetic storms, that it may not be amiss to explain that the two storms were selected before the appearance of Dr. Chapman's paper. The storm of March 7–8 was suggested by the kindness of the Director of the Meteorological Service of Canada in sending me, unasked, copies of the D (declination), H (horizontal force), and V (vertical force) curves from Agincourt (near Toronto). Eskdalemuir curves for that date and also for the second storm, which occurred on August 15–16, were kindly supplied by Dr. Crichton Mitchell. The Eskdalemuir magnetographs record N (north component) and W (west component), instead of H and D as at Kew and Agincourt. The simplest way to a comparison was to calculate H and D changes at Eskdalemuir from the observed N and W changes.

The two storms are undoubtedly of the kind discussed by Dr. Chapman, according to whom‡ "apparently all great world-wide magnetic storms commence simultaneously to within a few seconds, over the whole earth, although small local fluctuations may sometimes mask the commencement at particular stations." All I think we can really say is that the particular form of disturbance known as a "sudden commencement," or Sc, which precedes a considerable number of world-wide storms, appears simultaneously at all stations, to the degree of accuracy with which time can be measured on ordinary curves. This conclusion has been reached independently by several recent investigators, including Dr. Chapman and myself.§ Accuracy to

* 'Roy. Soc. Proc.,' A, vol. 94, p. 525.

† 'Roy. Soc. Proc.,' A, vol. 95, p. 61.

‡ *Loc. cit.*, p. 62.

§ 'Proc. Phys. Soc.,' London, vol. 23, p. 49; vol. 26, p. 137.

half-a-minute in time measurements is a high claim, and the instant at which a movement becomes visible is not wholly independent of the sensitiveness of the instrument. If Dr. Chapman is correct in stating that all world-wide storms commence simultaneously, we must I think suppose that all have Sc's. If so, these must be "masked" more often than not. The existence of an Sc is important in relation to the question whether storms recur after a definite interval. When Mr. W. Maunder* claimed to have established a 27·3-day recurrence period, this aspect of the case was dealt with in a review of his paper which I contributed to "Terrestrial Magnetism."† Of the 276 storms in Mr. Maunder's list for the period 1882 to 1903 only 77, or 28 per cent., were credited by him with an Sc. In many cases of world-wide storms disturbance seems to originate gradually. The storm of December 16–17, 1917, is a case in point. On that occasion the growth of disturbance was so rapid that I concluded "its commencement may be accepted without hesitation as occurring between 8 h. and 9 h." Often, however, differences of several hours occur in the estimate of the time of commencement made at different stations. Also, an Sc is only sometimes immediately followed by large disturbance. Often a comparatively quiet time intervenes between the Sc—which possesses at most stations a characteristic form—and the large movements, which in the absence of an Sc would be recognised as a storm. In some cases there is room for doubt whether there is a real connection between the Sc and the subsequent storm. There is all the more reason for hesitation on this point because, in a considerable number of cases, the Sc itself is the principal movement. It is followed in some instances by what I have described as a "crest." In low or mean latitudes the Sc is mainly an H movement and is seldom visibly oscillatory, H undergoing a considerable rise in the course of a few minutes. The "crest" consists essentially in the maintenance of the enhanced value of H, the curve presenting a nearly level ridge for a considerable time, which may amount to several hours. A rapid fall, somewhat like an inversion of the original Sc, then ensues, and there may be no further disturbance worth mentioning.

If an Sc were always the immediate precursor of large movements, and if these took an invariable or nearly invariable course, similar stages in the development being reached after definite intervals, there would be much to be said for Dr. Chapman's "storm time," or time measured from the beginning of the storm. If, however, as I suspect to be nearer the truth, the sequence of events is by no means uniform, even in storms having Sc's, the deduction after Dr. Chapman's method of mean results derived from a number of storms

* 'Monthly Notices, R. A. S.,' vol. 65, p. 2.

† 'Terrestrial Magnetism and Atmospheric Electricity,' vol. 10, p. 9.

superposed according to "storm-time," may give origin to data of uncertain physical significance. It may be a case of combining essentially heterogeneous material.

In connection with the discussion of the magnetic results of the Antarctic Expedition of 1911–12, I have studied the records of many magnetic storms at eight or ten stations, and, during the last 20 years, records of many storms at Kew, Falmouth, and Eskdalemuir have come under my notice. There are certain features which tend to be common, including the well-known depression in H, most usually experienced sooner or later in large storms, and the modification and great enhancement of the diurnal variation in V—first described, I believe, in the case of Kew Observatory—but the phenomena, while markedly influenced by local time, have been very variable as regards "storm time."

§ 2. The two storms now to be discussed, unlike that of December 16–17, 1917, have prominent Sc's; also large disturbance immediately followed. I have preferred, however, to refer them to ordinary G.M.T. hours, principally for reasons already stated, but partly for the practical reason that the time-breaks in the curves favour that course.

The curves of December 16–17, 1917, were measured at 4-minute intervals, mainly with a view to a special enquiry into Bidlingmaier's "Magnetic Activity." The labour involved in 4-minute measurements is great, and when there are large short-period oscillations, as in the two storms of 1918, individual measurements are apt to be uncertain, as a difference in the setting of the scale equivalent to 1 minute of time may answer to a large difference of ordinate. Accordingly, on the present occasion I have estimated mean hourly values, using a scale in the way originally introduced at Potsdam. This method has been used when measuring electric potential curves at Kew for a number of years, with satisfactory results. In careful hands it gives wonderfully consistent results, even with highly oscillatory curves.

The mean hourly values during the two storms are given in Tables I and II as differences from certain standard values. Details as to the ranges during the Sc's and the whole disturbance, and as to instantaneous and mean values for certain specified times, are given in Tables III and IV. All declination data are given in terms of the equivalent force. The difficulty of settling standard or normal values was discussed in my previous paper. As my information for Agincourt and Eskdalemuir was confined to the curves received, and uniformity of procedure was desirable, I have accepted as the normal value in each case the mean from 2 h., 8 h., 14 h., and 20 h. L.M.T. during the 24 hours preceding the storm. The mean from these

Table I.—Mean Hourly Values. March 7–8, 1918.

Hour, G.M.T.	Eskdalemuir.					Kew.			Agincourt.		
	N.	W.	H.	D.	V.	H.	D.	V.	H.	D.	V.
	γ.	γ.	γ.	γ.	γ.	γ.	γ.	γ.	γ.	γ.	γ.
20.5	− 4	− 5	− 5	− 4	+ 3	+ 3	+ 2	+ 5	+ 6	+ 16	0
21.5	+ 23	+ 1	+ 22	− 6	0	+ 28	0	+ 5	+ 35	+ 15	+ 1
22.5	+ 5	− 16	0	− 17	− 4	+ 12	− 9	0	+ 38	+ 10	+ 2
23.5	− 22	− 51	− 36	− 42	+ 10	− 25	− 31	+ 3	+ 12	+ 21	+ 5
0.5	− 80	−101	−106	− 73	− 62	− 49	− 58	− 14	+ 75	+ 46	+ 67
1.5	−149	−187−	−197−	−135	−205−	− 35	−107	− 74	+ 95	+ 4	−100
2.5	−263−	−259−	−327−	−170	−205−	−136	−175	−142	+205+	+ 39	−179
3.5	−164−	−165	−205−	−110	−134	−148	−101	− 94	−107−	− 20	−130
4.5	−159	− 16	−157	+ 31	− 98	−112	+ 32	− 43	−217−	− 58	−121
5.5	− 52	− 32	− 59	− 15	− 39	− 80	− 12	− 18	− 37	− 27	+ 21
6.5	− 57	− 35	− 65	− 17	− 6	− 77	− 9	− 3	− 83	+ 13	+ 17
7.5	− 67	− 40	− 76	− 18	+ 5	− 77	− 11	+ 3	−181	+ 75	− 28
8.5	− 75	− 35	− 82	− 11	+ 9	− 80	− 6	+ 8	− 90	+ 18	− 6
9.5	− 77	− 32	− 83	− 8	+ 11	− 83	− 3	+ 18	− 61	− 6	+ 7
10.5	− 79	− 27	− 83	− 3	+ 15	− 83	+ 9	+ 19	− 63	+ 6	+ 14
11.5	− 85	− 19	− 87	+ 7	+ 21	− 94	+ 14	+ 21	− 56	− 1	+ 17
12.5	− 76	− 14	− 77	+ 9	+ 24	− 88	+ 18	+ 26	− 53	− 9	+ 20
13.5	− 71	− 13	− 72	+ 9	+ 27	− 83	+ 17	+ 29	− 55	− 13	+ 20

Table II.—Mean Hourly Values. August 15–16, 1918.

Hour, G.M.T.	Eskdalemuir.					Kew.		
	N.	W.	H.	D.	V.	H.	D.	V.
	γ.	γ.	γ.	γ.	γ.	γ.	γ.	γ.
14.5	− 20	+ 29	− 11	+ 34	− 7	− 10	+ 39	− 2
15.5	+ 10	+ 18	+ 15	+ 14	− 7	+ 18	+ 49	+ 5
16.5	+ 28	+ 68	+ 47	+ 57	− 10	+ 47	+ 55	− 3
17.5	+ 97	+ 72	+114	+ 40	0	+ 87	+ 37	+ 22
18.5	+184	+122	+212	+ 62	+ 22	+152	+ 40	+ 70
19.5	+ 90	+ 40	+ 98	+ 12	+ 83	+ 47	− 3	+ 80
20.5	+140	+ 55	+150	+ 11	+136+	+ 25	− 2	+102
21.5	− 9	− 5	− 10	− 2	+ 36	− 9	− 9	+ 51
22.5	− 60	− 66	− 77	− 45	− 48	− 37	− 46	+ 14
23.5	+ 5	− 39	− 7	− 39	− 12	− 21	− 36	+ 11
0.5	− 3	− 42	− 15	− 39	+ 11	− 26	− 33	+ 13
1.5	− 10	− 28	− 18	− 24	+ 17	− 29	− 18	+ 13
2.5	− 62	− 9	− 62	+ 10	− 6	− 40	+ 10	+ 10
3.5	− 83	− 16	− 84	+ 9	− 81	− 42	+ 12	− 2
4.5	− 56	− 19	− 59	− 2	− 57	− 45	+ 1	− 10
5.5	− 21	− 10	− 23	− 3	− 33	− 22	− 7	− 2
6.5	− 15	− 29	− 23	− 23	− 8	− 22	− 17	+ 6
7.5	− 13	− 29	− 21	− 24	+ 7	− 21	− 22	+ 14

four hours in the average day comes very near the mean for the day in all the magnetic elements. Greenwich time was accepted as local time for Kew (51° 28′ N.; 0° 19′ W.) and Eskdalemuir (55° 19′ N.; 3° 12′ W.), and time

Table III.—Ranges.

	March 7–8.									August 15–16.					
	Eskdalemuir.			Kew.			Agincourt.			Eskdalemuir.			Kew.		
	H.	D.	V.	H.	D.	V.	H.	D.	V.	H.	D.	V.	H.	D.	V.
	γ.	γ.	γ.	γ.	γ.	γ.	γ.	γ.	γ.	γ.	γ.	γ.	γ.	γ.	γ.
Sc movement	85	4	8	61	22	?	108	53	14	215	76	14	136	62	?
Whole storm	404+	273+	218+	239	221	179	672+	582	501	557	252	280+	338	165	184

Table IV.—Values of H (Departures from Normal Value).

	March 7–8.						August 15–16.			
	Eskdalemuir.		Kew.		Agincourt.		Eskdalemuir.		Kew.	
	γ.	h. m.	γ.	h. m.	γ.	h. m.	γ.	h. m.	γ.	h. m.
Instantaneous Values.										
Extreme Sc value	+ 76	21 15	+ 58	21 15	+ 69	21 15	+173	15 52	+113	15 52
Highest value	+ 76	21 15	+ 58	21 15	+210+	1 0 to 3 10	+425	18 22	+283	18 28
Lowest value	−328−	2 10 to 3 10	−181	3 15	−462−	3 30 to 4 15	−132	22 22	− 55	22 22 or 2 35
Mean Hourly Values and commencing times.										
Starting with Sc	+ 27	21 10	+ 32	21 10	+ 37	21 10	+ 57	15 50	+ 43	15 50
Highest value	+ 27	21 11	+ 32	21 11	+207+	2 10	+227	17 40	+160	17 40
Lowest value	−328−	2 10	−172	2 25	−360−	3 30	{−83, −82}	{21 55, 2 32}	− 49	3 35

of 75° W. as local time for Agincourt (43° 47′ N.; 79° 16′ W.). This procedure was less satisfactory for the August than the March storm, because August 14 was slightly disturbed, and the afternoon V-trace at Eskdalemuir was more affected than is usual with so comparatively trifling a disturbance. The Sc on March 7 began about 21 h. 10 m. G.M.T., and that on August 15 about 15 h. 50 m. The first hours included in Tables I and II entirely precede the storm, and anyone who prefers the values from these hours as standards can easily make the necessary changes in the Tables. The mean value of H for the hour commencing at the Sc will be found in Table IV by anyone desiring a more exact comparison with Dr. Chapman's results.

An unfortunate feature on both occasions was loss of trace at Eskdalemuir. There was also loss of H-trace at Agincourt, where the oscillations were so large that the trace went off the sheet on both sides. The absence of the trace from the Agincourt sheet was short, except between 2 h. 10 m. and 3 h. 10 m. G.M.T. on the plus side, and between 3 h. 30 m. and 4 h. 15 m. on the minus side; but during these intervals the marginal values—which had to be accepted as the true values—may have been considerably exceeded. This is indicated by the + sign attached to the entry under 2.5 h., and by the − sign attached to the entries under 3·5 h. and 4·5 h. in Table I. The values for the adjacent hours are slightly affected, but are probably nearly correct. At Eskdalemuir, on August 15, the V-trace was off the sheet on the plus side between 20 h. and 21 h., but only for a short time, and the excess over the marginal value was probably small; still, the entry in Table II is an underestimate. On March 7–8 the loss at Eskdalemuir was more serious. It happened to be the second day's trace, so the curves naturally started below the middle of the sheet, and all three elements had, unfortunately, an exceptionally large fall. The N- and W-traces were off the sheet on the minus side several times, and for over an hour continuously in either case. The V-trace was off only once, but then for two hours. Thus, in accepting the marginal value, a very considerable underestimate was probably made of the depression, and so of the range of force during the storm. The hourly values in Table I, to which the minus sign is attached, ought probably to be very considerably lower.

A general idea of the sequence of events is most easily derived from fig. 1. There is a sensible resemblance between the H-curves for March 7–8 at Kew and Eskdalemuir and the H-curves in Chapman's fig. 1. There is the characteristic rise in H for the first hour or half-hour of the storm, and then a marked fall. But whereas the rise in the mean value for the first hour is not so very much larger than Chapman's, the subsequent fall is enormously

greater, and takes place in shorter time. Chapman,* it is true, remarks on an "increasing lateness of the epoch of minimum horizontal force, with

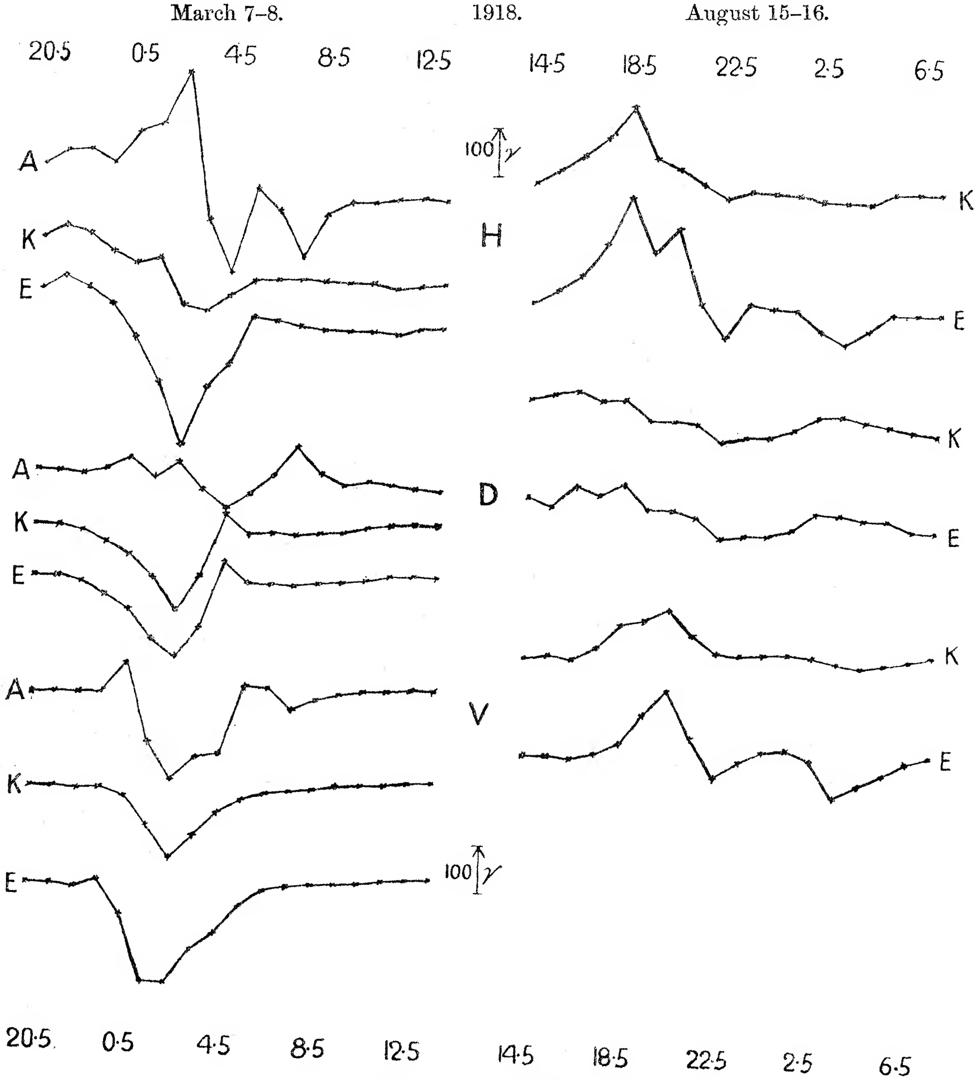

Fig. 1.—Times are G.M.T.

A = Agincourt. K = Kew. E = Eskdalemuir
H = Horizontal Force. D = Declination. V = Vertical Force

diminishing storm intensity," which implies an acceleration when disturbance is large.

The question as to whether mere size affects the phase of magnetic storms

* *Loc. cit.*, p. 72.

arose incidentally in the discussion of Mr. Maunder's results already referred to. He had divided storms into four classes according to size. Taking his classes in descending order of magnitude, and accepting his figures, I found the respective average durations to be 29·1 h., 34·4 h., 33·9 h., and 26·2 h., and concluded, "if we exclude the very largest disturbances, whose number is very limited (16 out of 276), we have apparently a distinct tendency for the duration to be least in the weaker storms." This is not necessarily incompatible with Chapman's conclusions, but it is decidedly against any marked acceleration of phase with increase of intensity. Unless Chapman himself had supposed the acceleration to be small, he would hardly have derived his results, as one infers he did, from the superposition of storms irrespective of their size.

While the Kew and Eskdalemuir H diagrams for March 7–8 have a resemblance to Chapman's fig. 1, it is otherwise with the Agincourt H diagram for the first part of the storm. We have, of course, the usual rise during the Sc, but, instead of falling, the general trend in H is upwards. The mean value for the sixth hour "storm-time" exceeded that for the first hour storm-time by at least 170 γ. The maximum at Agincourt occurred practically simultaneously with the minimum at Kew and Eskdalemuir.

Chapman seems to regard the pole of the zonal harmonic of the first order in the Gaussian potential as decisive in the phenomena of magnetic storms. It is obviously fundamental in the Birkeland-Störmer theory, because the paths of the electrical ions or corpuscles coming from the sun are determined by the earth's magnetic field, and at distances from the earth large compared with the earth's radius, the first order terms in the potential will naturally predominate. But when we come to the actual distribution of electrical currents in aurora, at heights of the order of 100 kilom., there is no such obvious reason for the supposed preponderance of the first order terms. Be this as it may, the interesting point at the moment is that, if we accept Chapman's position (80° N., 70° W.) for the magnetic pole (from the zonal harmonic), we find for the magnetic latitudes of Agincourt, Kew, and Eskdalemuir the respective values 53·6°, 53·9°, and 57·9°. Thus Agincourt and Kew have practically the same magnetic latitude. Consequently, in accordance with Chapman's views, we should naturally expect the disturbance phenomena at the two places to be similar. There is, of course, five hours' difference in the local time, and it may be suggested that the difference in the H variations represents Chapman's "local storm variation," by which he means apparently the difference between the diurnal variations characteristic of disturbed and ordinary

days. I have shown, however, in the case of Kew*—and other European stations agree—that the type of the diurnal variation in H on disturbed days makes no very great departure from that for ordinary days, and the changes during the six hours commencing at 21 h. are small. Thus the true explanation of the difference remains to be found.

§ 3. Dr. Chapman's statement† as to the later phenomena in H—" A period of recovery then follows, and lasts for several days. Both the decrease and the recovery proceed most rapidly after their initial stages, and gradually slow down "—is I think a fair statement of the average facts; but the recovery is not very marked in fig. 1, and is irregular, as is usual in individual cases. His further statement‡ " This recovery shows itself in the non-cyclic variation on quiet days " is I think premature. This explanation of the large n.c. rise in H on quiet days naturally suggests itself, and was in fact pointed out in my first paper§ describing the phenomenon. But in a subsequent paper‖ I mentioned a second possibility, which so far as I know has not yet been disproved. The phenomena are rather suggestive of what happens with a permanent magnet, especially if of steel of poor retentiveness and recently magnetised, when subjected to a magnetic, mechanical, or thermal shock. There is an immediate loss of magnetic moment, with a tendency to recovery during a subsequent rest. The loss is determined partly by the magnitude of the shock, partly by the recent history of the magnet. The rise of moment during the rest may be a consequence of the fall occasioned by the shock. On the other hand, the fall consequent on the shock may arise from the moment of the magnet having been previously raised above a reasonably stable position. It is conceivable that, owing to the earth's rotation, or some other property, the horizontal intensity has a tendency to rise above what is altogether stable, a tendency which manifests itself in the n.c. change in quiet days, and that the decrease characteristic of magnetic storms is a shock effect, really the consequence of this.¶ The two explanations are not necessarily exclusive; each may be partly true. At present I can only say that conclusive evidence one way or another is not so easily got as might be supposed *à priori*. The two storms under consideration are well adapted to illustrate the difficulties. The observed n.c. H changes on all the early days in March to which " character " 0 was allotted at Kew were as follows:

* 'Phil. Trans.,' A, vol. 210, pp. 283, 286 and 290.

† *Loc. cit.*, p. 62.

‡ *Loc. cit.*, p. 66.

§ 'British Association Report for 1895,' p. 209 (specially p. 212).

‖ 'British Association Report for 1896,' p. 231 (specially p. 237).

¶ Since this was written I have found a very similar suggestion in § 129 of Balfour Stewart's article on Terrestrial Magnetism in the 'Encyclopædia Britannica,' 9th edition.

$+7\gamma$ on 5th, -2γ on 6th, $+13\gamma$ on 9th, -5γ on 13th, and $+5\gamma$ on 14th. We thus get $+2{\cdot}5\gamma$ as the mean from the two quiet days preceding the storm, and $+4{\cdot}3\gamma$ as the mean from the three days which followed it. During the 10th, 11th, and 12th, all days of "character" 1, there was a total n.c. rise of $+29\gamma$. The 15th and 16th were days of "character" 2. The depression, about 44γ, existing at 24 h. on March 8 was thus practically accounted for before the next large disturbance began, but the greater part of the apparent recovery took place on days of "character" 1.

On August 16 we have regarded the storm as practically ended by 8 h., because that is what is naturally suggested by the appearance of the curves between 5 h. and 8 h. But shortly after 8 h. a very rapid fall took place in H at Kew and in N at Eskdalemuir. By 10 h. H at Kew had fallen to 153γ below what we have accepted as standard value. If we regarded this as part of the storm which commenced on the 15th, it would raise the H range at Kew from 338γ to 436γ, and diminish the lowest mean hourly value from -49γ to -132γ. But this fall in H was followed by so large and rapid a rise that practically no depression remained by the end of the day. There was a very quiet time on both the 15th and 17th from 1 h. to 5 h., and if we derive mean values of H from these four hours we find the value on the 15th only $4{\cdot}5\gamma$ in excess of that on the 17th. There immediately followed—a very unusual feature after large storms—seven consecutive days to which "character" 0 was awarded at Kew. The successive n.c. changes were $+11\gamma$, $+9\gamma$, $+8\gamma$, -9γ, $+8\gamma$, -3γ, and $+8\gamma$. This represents a net rise of 32γ, or 27γ in excess of the apparent depression remaining on the morning of the 17th. The mean of the n.c. changes from these seven days is about the average for quiet days. In calculating these n.c. changes mean ordinates from 60 minutes centering at the hour were accepted for the respective midnights, and it was assumed that there was no real change in the base value of the curves after making due allowance for the temperature changes in the magnetograph room. In view of facts such as the above, one can only recommend caution in accepting as final any conclusions as to the cause of the dominant n.c. change in H on quiet days.

§ 4. Reverting to fig. 1, the very close resemblance between the D changes at Kew and Eskdalemuir should be noticed. As Table III shows, D had a very much bigger range at Agincourt on March 7–8 than at Kew or Eskdalemuir, but the oscillations at Agincourt were much more nearly about a mean value, and if we had before us only mean hourly values we should greatly underestimate the disturbance. It is noteworthy that the extreme easterly position at Agincourt in fig. 1 synchronises with the extreme westerly position at Kew and Eskdalemuir.

On March 7–8 the V curves at Kew and Eskdalemuir show the depression characteristic of the early morning hours during magnetic storms, while on August 15–16 they show the elevation characteristic of the afternoon. It appears, however, decidedly later in the day than usual.* On March 7 the afternoon elevation is practically absent at Kew and Eskdalemuir—possibly on account of the late hour when the storm began—and is but poorly represented at Agincourt, though the storm began there near 16 h. L.M.T. A somewhat unusual feature—represented, however, in the storm of December 16–17, 1917—is the double bay in the Eskdalemuir V-trace in the night of August 15–16.

Mean hourly values by themselves may give an inadequate idea of the activity of the disturbance. Table I, for instance, might almost suggest that on March 7–8 declination was less disturbed at Agincourt than Kew. The figures for the hourly ranges in Tables V and VI will help to a truer conception of the facts. During the most active part of the storm, from 0 h. to 5 h. G.M.T. on March 8, the hourly ranges were enormously greater at Agincourt than Kew. H at Kew is 15 per cent. higher than at Agincourt, so the excess in the angular movements at Agincourt was even

Table V.—Hourly Ranges. March 7–8, 1918.

Hour, G.M.T.	Eskdalemuir.			Kew.			Agincourt.		
	N.	W.	V.	H.	D.	V.	H.	D.	V.
	γ.	γ.	γ.	γ.	γ.	γ.	γ.	γ.	γ.
20–21	10	9	1	6	5	—	10	6	1
21–22	82	28	7	59	24	—	110	59	13
22–23	73	95	15	77	59	—	53	48	12
23–24	29	35	19	30	24	—	43	29	11
0–1	150	91	117	76	46	32	163 +	134	110
1–2	194 +	197 +	84 +	97	163	96	360 +	582	507
2–3	174 +	80 +	—	194	102	45	264 +	279	125
3–4	196 +	165 +	130 +	71	220	88	672 +	529	310
4–5	241	152	67	107	88	—	494 +	154	304
5–6	98	77	54	35	40	—	115	65	36
6–7	65	59	21	35	32	—	91	48	27
7–8	70	45	6	32	32	—	101	92	57
8–9	45	49	6	24	35	—	84	48	38
9–10	40	40	6	30	35	—	43	36	14
10–11	116	112	13	65	54	—	103	59	37
11–12	41	32	8	21	16	—	48	33	17
12–13	25	17	5	18	8	—	22	24	7
13–14	18	12	3	15	11	—	24	12	7

* The usual hour of the maximum in V on disturbed days at Kew Observatory is from 17 h. to 18 h. See 'Phil. Trans.,' A, vol. 210, pp. 284–286.

Table VI.—Hourly Ranges. August 15–16, 1918.

Hour, G.M.T.	Eskdalemuir.			Kew.	
	N.	W.	V.	H.	D.
	γ.	γ.	γ.	γ.	γ.
14–15	15	10	5	18	10
15–16	181	134	14	136	64
16–17	70	38	11	41	19
17–18	263	153	39	183	67
18–19	316	161	42	221	40
19–20	92	67	64	40	51
20–21	385	291	131 +	88	113
21–22	89	70	89	52	72
22–23	99	67	81	28	56
23–24	30	16	59	12	16
0–1	40	24	4	19	27
1–2	24	18	8	19	13
2–3	80	43	93	31	44
3–4	32	23	14	31	21
4–5	30	16	32	17	11
5–6	31	27	21	18	16
6–7	20	12	25	18	11
7–8	25	38	8	15	29

greater than Table V suggests. The total range there was approximately 2° 5′, and the lowest instantaneous value was nearly 80′ below what we have accepted as standard. The deduction of maximum and minimum hourly values for H and D from N and W curves is hardly practicable, so N and W data had to be given for Eskdalemuir in Tables V and VI. Owing to the loss of trace already mentioned, some of the ranges in the Tables are under-estimates, and no value at all could be assigned for V at Eskdalemuir between 2 h. and 3 h. on March 8, because the trace was off the sheet all the time. At Kew the artificial disturbance in V forbids the deduction of hourly ranges unless the natural disturbance is large. Values for that element are thus confined to the four most disturbed hours of March 8. They are mainly intended to show the comparative insignificance of the disturbance at Kew.

§ 5. Measurements were made of some of the most rapid rates of change with the following results:—

March 7–8—

Eskdalemuir......	N	$+57$ (1), $+16$ (5), -57 (2), ± 21 (14), ∓ 41 (6), ∓ 23 (7);
„	W	$+27$ (1), -23 (5), ∓ 40 (6), ∓ 16 (8);
„	V	-10 (10), $+13$ (7);
Kew	H	$+41$ (1), $+12$ (5), -10 (16), ∓ 19 (6);
„	D	-7 (16), -8 (11), ∓ 17 (6);
Agincourt.........	H	∓ 58 (9), -47 ($7\frac{1}{2}$), -89 ($7\frac{1}{2}$), $+26$ (10);
„	D	-34 (15), $+52$ (9), ∓ 115 (8);
„	V	-28 (9), $+22$ (7), -24 (12), ± 23 (19), ∓ 57 (8).

August 15–16—

Eskdalemuir......	N	$+184$(1), -258(1), $+24$(11), ∓ 43(12), -16(11), $+15$ (24), -22 (10), $+40$ (3), -136 (2);
„	W	$+134$ (1), -145 (1), -88 (3), $+21$ (9);
Kew	H	$+139$(1), -183(1), $+14$(11), -9(11), $+11$ (23), -14 (14);
„	D	$+56$ (1), -67 (1), $+12$ (9).

The figure outside the bracket gives the rate, the unit being 1 γ per minute. The figure inside the bracket gives the duration in minutes of the interval during which the change occurred. The plus sign signifies a numerical rise in H, N, W, and V, or westerly movements in D, the minus sign the reverse. The double sign implies an oscillation, the upper sign applying to the first, the lower to the second movement. For instance, ± 21 (14) means that the element first increased and then diminished, the times taken to rise and fall together amounting to 14 minutes; 21 represents the result obtained when the numerical sum of the two movements, expressed in terms of 1 γ as unit, is divided by 14. Rates from very short intervals, *e.g.*, $+57$ (1), have a large probable error, as no very exact time measure of so short an interval is possible. The time of an oscillation, especially when the to-and-fro movements are nearly equal, can be measured more accurately than that of a unidirectional movement. In some cases estimates have been given for the separate movements, as well as for the total movement during an oscillation. Most of the estimates were based on measurements made on actual turning points of the curves, but sometimes, where the rate of change fell off markedly near a turning point, the most rapid portion only of the movement was considered. On August 15–16 the very rapid rises of force from 1-minute intervals refer to the rising movement in the Sc, while the very rapid falls

from 1-minute intervals refer to a remarkable movement which occurred nearly 1 h. 40 m. after the Sc.

A remark by Dr. Chapman* "The irregular and rapidly changing magnetic variations during a storm are of generally local character" is, I think, true of most very large rapid oscillations. At all events it is usually in such cases that outstanding differences are seen between Kew and Eskdalemuir, or between Antarctic and ordinary latitudes; but it does not apply to Sc movements except in a limited sense. The cause of these movements is operative from pole to pole, and is so effective even near the equator that Prof. Birkeland mistakenly supposed them to be principally developed there. At the same time, the great difference in the amplitude at stations so near together as Kew and Eskdalemuir, and the much greater relative development of the first or falling movement of the oscillation at Eskdalemuir and Agincourt, as compared with Kew, show that the immediate cause must be largely dependent on the geographical position of the station.

§ 6. The principal use made of Tables V and VI was in calculating Bidlingmaier's "Magnetic Activity." This is defined for a particular station as the mean value of $(1/8\pi)(\alpha^2+\beta^2+\gamma^2)$, where α, β, γ denote the departures of the three rectangular components of magnetic force from their standard values. It consists of two parts, called A_1 and A_2 in my previous paper.† A_1 represents what the "activity" would be if during each hour each element remained constantly at its mean value for that hour. A_2 is the contribution to the "activity" from the variations within the hour. In my last paper I calculated A_2 from the formula

$$A_2 = (1/8\pi)(1/n)\Sigma\eta^2, \qquad (1)$$

where the n values of η represented the departures from the mean value for the hour of the values obtained from measuring the curves at intervals of $60/n$ minutes. Bidlingmaier's original proposal was to derive A_2 from the hourly range, through certain arbitrary relations based on measurements of the Wilhelmshaven curves. In a discussion‡ of this proposal I pointed out that Bidlingmaier's relations, if accepted, would have the undesired effect of making the calculated value of A_2 depend on the sensitiveness of the magnetograph, and that the only obvious way of avoiding this was to assume

$$(1/n)\Sigma\eta^2 = CR^2, \qquad (2)$$

where R is the hourly range and C a constant. From an examination of term-hour curves from a large number of observatories I found that when R

* 'Monthly Notices, R. A. S.,' vol. 69, p. 74.

† 'Roy. Soc. Proc.,' A, vol. 94, p. 540.

‡ 'Terrestrial Magnetism and Atmospheric Electricity, vol. 22, p. 57.

was derived from the largest and least hourly ordinates resulting from measurement of the curves at 5-minute intervals, the best value for C lay between 0·09 and 0·10. In a paper in the same number of 'Terrestrial Magnetism,' Mr. D. L. Hazard* arrived independently at a very similar result from a study of Cheltenham curves. He proposed 0·10 as the value of C. I found that the appropriate value for C fell when the range was derived, not from measurements at regular time intervals, but from the actual maximum and minimum ordinates within the hour. In calculating A_2 from Tables V and VI, I have taken 0·09 as the value of C; *i.e.*, I have assumed.

$$A_2 = (1/8\pi)(0{\cdot}3\,R)^2. \tag{3}$$

The difficulty of fixing a normal value in calculating A_1 was pointed out in my last paper, where two calculations were made. One set of results, described as A_1, accepted for the normal the mean value from a quiet period of 24 hours preceding the storm; the other set, described as A'_1, accepted the mean value for the 24 hours of the storm day itself. The latter choice was impossible in the present case owing to loss of trace. Thus only one set of values was found for A_1, which accept the normal values already explained in connection with Tables I and II.

In the case of the hourly values in Tables VII and VIII, A_1 and A_2 are not given separately, but only their sum. But the mean values at the foot include separate values for A_1 and A_2 as well as for A_1+A_2. These means are in each case derived from the 17 last hours included in the Tables, the hour preceding the storm being left out of account. Apparent inconsistencies of 1 unit in the last place are due to the fact that the calculations were carried to one figure beyond the last retained. The trace being off the sheet from 2 h. to 3 h. on March 8 at Eskdalemuir, 0 had to be assigned as the contribution from V to A_2. The other entries to which a + is attached also suffered from loss of trace. Probably A_2 suffered more than A_1 as a rule. At the same time, the percentage of the total "activity" for the horizontal plane at Eskdalemuir due to A_2 in Table VII is practically the same as at Kew, where there was no loss of trace. This percentage is only 9 at these two stations as compared with 37 at Agincourt. In Table VIII the percentage contribution from A_2 is considerably larger at Kew and Eskdalemuir than it was in Table VII, being 28 for the horizontal field at Eskdalemuir and 19 at Kew. The contribution from V is substantial in both Tables, though much less important relatively than in the storm of December, 1917.

The contribution from V to A_1 at Kew on August 15–16 is not given in the Table. The mean from the 17 hours was actually 61, bringing up the

* 'Terrestrial Magnetism and Atmospheric Electricity,' vol. 22, p. 84.

Table VII.—" Magnetic Activity," March 7–8, 1918. (Unit 1×10^{-10} erg per cubic centimetre.)

Hour, G.M.T.	Eskdalemuir.					Kew.					Agincourt.				
	N.	W.	V.	N + W.	N + W + V.	H.	D.	V.	H + D.	H + D + V.	H.	D.	V.	H + D.	H + D + V.
20–21	1	1	0	2	3	1	0	—	1	—	2	10	0	12	12
21–22	45	3	0	48	48	44	2	—	46	—	92	22	1	114	115
22–23	20	43	1	63	64	27	16	—	43	—	68	12	1	80	80
23–24	22	108	5	130	135	28	40	—	68	—	12	20	1	32	33
0–1	335	435	202	771	973	116	141	11	258	269	319 +	148	222	467 +	689 +
1–2	1018 +	1530 +	1697 +	2549 +	4246 +	82	551	251	633	884	823 +	1216	1318	2040 +	3358 +
2–3	2861 +	2692 +	1672 +	5553 +	7225 +	871	1256	810	2127	2936	1922 +	338	1331	2260 +	3590 +
3–4	1208 +	1181 +	775 +	2389 +	3164 +	890	579	379	1469	1848	2073 +	1016	1017	3089 +	4106 +
4–5	1214	93	398	1307	1705	540	69	—	609	—	2747 +	218	914	2965 +	3879 +
5–6	142	62	71	204	275	259	11	—	270	—	102.	44	22	146	168
6–7	144	61	3	206	209	240	7	—	247	—	304	14	14	318	332
7–8	196	71	1	267	268	240	8	—	248	—	1340	258	43	1598	1641
8–9	231	57	3	288	292	257	6	—	263	—	348	17	7	365	371
9–10	242	46	5	288	293	277	5	—	282	—	155	6	3	161	164
10–11	296	74	10	370	380	289	14	—	303	—	196	14	13	210	223
11–12	294	18	18	311	329	353	9	—	362	—	133	4	13	137	150
12–13	232	9	23	241	264	309	13	—	322	—	114	5	16	119	135
13–14	202	7	29	209	238	275	12	—	287	—	122	7	16	129	146
Means															
$A_1 + A_2$	512	382	289	894	1183	300	161	—	461	—	639	198	291	837	1128
A_1	462	351	279	813	1092	281	138	93	419	512	430	36	189	529	719
A_2	50	30	10	81	90	19	23	—	42	—	209	162	102	308	409

Table VIII.—"Magnetic Activity," August 15–16, 1918. (Unit 1×10^{-10} erg per cubic centimetre.)

Hour, G.M.T.	Eskdalemuir.					Kew.		
	N.	W.	V.	N + W.	N + W + V.	H.	D.	H + D.
14–15	17	34	2	51	53	5	61	66
15–16	121	77	3	199	201	79	110	190
16–17	49	189	4	238	243	94	122	216
17–18	623	290	6	913	919	422	71	492
18–19	1707	686	26	2393	2418	1096	69	1165
19–20	353	80	289	433	722	94	10	103
20–21	1312	424	798 +	1737	2535 +	53	46	99
21–22	32	19	80	50	130	13	22	35
22–23	179	190	115	368	483	57	96	153
23–24	4	62	18	66	84	18	53	71
0–1	6	72	5	78	83	28	46	74
1–2	6	32	12	38	50	35	13	48
2–3	176	10	32	186	218	67	11	78
3–4	278	12	262	290	552	74	7	81
4–5	128	15	133	144	277	82	1	82
5–6	21	7	45	28	73	20	3	23
6–7	10	34	5	44	49	20	12	32
7–8	9	39	2	48	50	18	22	41
Means								
$A_1 + A_2$	295	132	108	427	535	134	42	176
A_1	212	95	97	306	403	108	34	142
A_2	83	37	11	120	131	25	8	33

mean value of A_1 from H, D and V combined to 203, or almost exactly half the corresponding result for Eskdalemuir. If we confine ourselves to the horizontal field, but take the complete activity $A_1 + A_2$, the Kew mean value was 52 per cent. of the Eskdalemuir value for the March storm, and 41 per cent. of the Eskdalemuir value for the August storm. The former percentage would, however, have been decidedly less but for the loss of trace at Eskdalemuir. These percentages are both less than in the corresponding case for December 16–17, 1917, but the higher is near the percentage obtained on that occasion when the contributions from V were included.

The mean "activity" at Agincourt on March 7–8 is only a little less than that for Eskdalemuir, whether V is included or not; but the Agincourt figures probably suffered less through loss of trace than those for Eskdalemuir. The mean "activity" for the August storm was decidedly less than that for the March storm at both Kew and Eskdalemuir. On these, as on many other occasions, the relative amplitudes of the disturbances were in no way proportional to the amplitudes of their Sc's.

In any comparison with the "activities" calculated for December 16–17, 1917, it is the A_1 not the A_1' figures that should be taken for the latter. If

we include V the mean "activity" at Eskdalemuir for the 17 hours of March 7–8 was only a shade larger than that for the 24 hours of December 16–17. If we take only the horizontal components the mean "activity" for December 16–17 was very considerably less than that for March 7–8 at both Kew and Eskdalemuir, though still larger than that for August 15–16, 1918. The largest mean hourly "activity" in any of the Tables is that for 2 h. to 3 h. on March 8 at Eskdalemuir. Through an underestimate, owing to loss of trace, it is 44 per cent. larger than the highest value observed on December 16–17, 1917.

Some conclusions can be drawn from the Tables as to the suitability of "magnetic activity," for the purpose for which it was primarily intended, viz., to supply a daily numerical measure of the disturbance at individual stations to replace the magnetic "character" figures 0, 1, 2 in the international scheme on which the selection of quiet days at De Bilt has depended. The chief use of these quiet days is for the calculation of the regular diurnal inequality, and if, as I have suggested, selected disturbed days should also be assigned for that purpose, or if for any reason inequalities should be wanted for several categories of days, it would be particularly important that the criterion employed should discriminate effectively between days having different types of diurnal inequality. Activity of oscillation which did not affect the mean hourly value would obviously be much less fatal to inequalities intended to represent moderately quiet days than would deflections raising or lowering the mean hourly value. On the other hand, if there are large oscillations, the effect on the mean hourly value must inevitably depend sensibly, however the curves are measured, on when the hour happens to fall. Days, in short, when there are large short-period oscillations provide unusual opportunities for the entry of "accidental" features into the diurnal inequality. The fact that A_1 is in general so much larger than A_2 is obviously a point in favour of "magnetic activity." It is also in its favour that on occasions when the oscillations are exceptionally large within the hour, as in the case of D at Agincourt on March 7–8, the contribution from A_2 becomes so large as to be vitally important. While recognising the advantageous features of "magnetic activity," I am doubtful whether they are an adequate offset against the large amount of labour entailed even with the simplified approximate way of calculating A_2 adopted here. I am still inclined to think that the use of absolute daily ranges, in the way which I have suggested elsewhere,* might as an international scheme give equally satisfactory results in a much simpler way.

§ 7. Some reference is needed to a criticism of "magnetic activity" under

* 'Terrestrial Magnetism and Atmospheric Electricity,' vol. 22, pp. 80–83.

another name recently made by Dr. Chapman.* Starting with the Maxwellian energy integral,

$$(1/8\pi)\iiint(\alpha^2+\beta^2+\gamma^2)\,dx\,dy\,dz, \tag{4}$$

he shows that if we write $\alpha_0+\delta\alpha$ for α, etc., the integral consists of the following three parts:—

$$(1/8\pi)\iiint \delta\alpha^2+\delta\beta^2+\delta\gamma^2)\,dx\,dy\,dz, \tag{5}$$

i.e., the space integral of Bidlingmaier's magnetic activity, which he calls the "self-energy integral";

$$(1/4\pi)\iiint(\alpha_0\delta\alpha+\beta_0\delta\beta+\gamma_0\delta\gamma)\,dx\,dy\,dz, \tag{6}$$

which he calls the "joint-energy integral"; and

$$(1/8\pi)\iiint(\alpha_0{}^2+\beta_0{}^2+\gamma_0{}^2)\,dx\,dy\,dz.$$

The last part, as a constant, he leaves out of account. Speaking of the first two parts, he says: "The latter (*i.e.*, the 'joint-energy integral') has usually been neglected on the ground that the permanent and disturbance fields being independent, on the average there will be no net gain or loss due to their superposition." This he holds to be unjustifiable, and concludes that the "joint-energy integral" is "the most important part of the whole excess energy."†

Later,‡ he says, after remarking on Lord Kelvin's estimate of the energy of a magnetic storm, "The other calculations which have been made have usually much underestimated the energy . . . the importance of the joint-energy integral was missed."

As Chapman gives no references, and does not explicitly mention "magnetic activity," I am uncertain whether he had in view the calculations of it made by myself and others, or whether he was referring to some attempts which I have not seen to calculate the energy of a magnetic storm from the "magnetic activity" alone.

"Magnetic activity" has the dimensions of energy, and in my first paper which was devoted to the method of calculating A_2, the word energy was used freely, but hardly in a way that could lead to misconception. In my paper in the 'Proceedings,' I was careful to use the term "magnetic activity," and pointed out that the Maxwellian integral "is supposed to be taken throughout the whole of the magnetic field. It takes, moreover, as point of departure a total absence of force. In the present case we know the

* 'Monthly Notices, R. A. S.,' vol. 79, p. 70.

† *Loc. cit.*, p. 73.

‡ *Loc. cit.*, p. 80.

absolute values . . . at a fixed point . . .; but the intensity of the field never vanishes." In short, I regarded Bidlingmaier's use as really distinct from Maxwell's, the latter's integral having simply suggested the final form adopted by Bidlingmaier, and particularly his use of the factor $(1/8\pi)$. The question now mooted by Chapman was raised during the discussion of my paper. To emphasise the difference from Maxwell, and the fact that only relative results were aimed at, I at one time thought of dropping the factor $1/8\pi$. The idea incorporated in "magnetic activity" was, however, Bidlingmaier's, and dropping a factor which he used would inevitably have caused confusion. Also, the use of the factor made the numerical results of more convenient magnitude. I had considered the integral (6), but saw no way of utilising it satisfactorily, believing that "any complete estimate of the expenditure of energy during a magnetic storm is probably impossible." This is an opinion I still retain, though I admire the mathematical powers exhibited in the calculation which Dr. Chapman has since actually made of the energy of a magnetic storm."

Even if the integral (6) should prove, as Chapman believes, of primary importance for the calculation of the energy of a storm, the quantity integrated seems useless as a criterion of the magnetic character of a day. This is more easily seen if we write the Maxwellian integral in the form

$$(1/8\pi)\iiint(\rho^2-\rho_0^2)\,dx\,dy\,dz+(1/8\pi)\iiint\rho_0^2\,dx\,dy\,dz, \tag{7}$$

where $$\rho^2 \equiv \alpha^2+\beta^2+\gamma^2,$$

and ρ_0 is the accepted standard value.

The first integral represents the sum of Chapman's "self-energy" and "joint-energy" integrals. If, with a view to characterising the days at a particular station, we took out mean daily values of $\rho^2-\rho_0^2$ the result would be sometimes positive, sometimes negative, the sign even often depending on whether V was excluded or not. During some highly disturbed days, owing to contributions from different hours cutting out, the resulting mean value would resemble that of a perfectly quiet day. In an international scheme, unless we treated results from individual stations as numerical, not algebraic quantities, we should have one station neutralising another. And as the distribution of stations is perfectly haphazard, so too would be the final result. The consequences of uncertainty as to the appropriate values for α_0, β_0, γ_0, pointed out in my previous paper in the case of "magnetic activity," would be much more serious in the case of the "joint-energy" term. An error of 1γ in the standard value adopted for any one of the elements would, in the ordinary day, swamp the contribution of the "magnetic activity" term. For the practical purposes of discriminating between different days the

E 2

superiority of Bidlingmaier's "magnetic activity" taken by itself seems hardly open to doubt.

If we aim at calculating the energy expended in a magnetic storm, I am disposed to agree with Dr. Chapman that the integral (6) must be taken into account, unless adequate reasons for neglecting it can be advanced. I do not, however, think that we have at present the knowledge requisite for dealing with the integral. The numerical results reached by Dr. Chapman seem to me to be determined mainly by what I cannot but consider the accident of the particular assumptions which he has made in order to obtain a definite mathematical problem capable of solution. A discussion of the more mathematical of these assumptions would be out of place here, but some remarks on the final physical assumption may be useful, especially as a possible use of the "magnetic activity" is suggested.

The value ultimately found by Chapman for his "joint-energy integral"—in comparison with which his value for the "self-energy integral" appears negligible—is*

$$H_0 (\delta_o H - \delta_i H)\, a^3,$$

where a is the earth's radius, $\delta_o H$ the mean value round the earth's equator of that part of the maximum depression of H due to external electric currents, and $\delta_i H$ the corresponding depression arising from internal currents. The relation between $\delta_o H$ and $\delta_i H$ is obviously of fundamental importance. The following is the only explanation I notice of the choice made: "It will be assumed that one-quarter of this variation (*i.e.*, of δH_0) is of internal and three-quarters of external origin. This division between the two sources is in general accordance with that which, in a study of the diurnal magnetic variations, I have found to hold good in their case."† No reference is given, but I presume reference is intended to Dr. Chapman's recent paper.‡ Referring to that source, the following is the clearest statement I can find:§ "The general result that the external field is about $2\frac{1}{2}$ times as great as the internal field, at the earth's surface, lies between the conclusions of Schuster (... 4, approximately) and Fritsche (... 1·5 approximately); van Bemmelen obtained still lower values."

Passing by the fact that the difference between the ratios 3 : 1 and 2·5 : 1 would answer to a difference of 25 per cent. in the calculated value of the energy, the large difference between the results of different investigators, and the far from good accordance of many of Dr. Chapman's observed and

* *Loc. cit.*, p. 77.
† *Loc. cit.*, p. 77.
‡ 'Phil. Trans.,' A, vol. 218, p. 1.
§ *Loc. cit.*, p. 35.

calculated values, suggest that the potential theory is not at present capable of giving very exact information as to the character of the regular diurnal variation, even within that portion of the earth's surface represented by Dr. Chapman's observations. All but four of his stations lay between 53° N. and 44° S., the two extreme being Pavlovsk 60° N., and Laurie Island 61° S. A less favourable opinion has been recently expressed by Miss A. van Vleuten* after an independent investigation of the problem, similar in comprehensiveness to Dr. Chapman's.

But, so far as I am aware, the results of all the investigators mentioned above, and one or two others mentioned by Miss van Vleuten, have referred to the regular diurnal variation on ordinary or quiet days. Even in comparatively low magnetic latitudes, *e.g.*, at Kew and Agincourt, the diurnal inequality in V is largely increased and modified on disturbed days. This is significant, in view of the explanation suggested by Dr. Chapman in the 'Philosophical Transactions,'† of why van Bemmelen's value for the ratio between the external and internal fields approached unity. In really high magnetic latitudes, judging by Antarctic results which there is no reason to suppose abnormal, the regular diurnal variation on highly disturbed days is almost of a different order of magnitude from that on quiet days. Until we have high latitudes adequately represented, we cannot judge whether a potential will give the regular diurnal variation there either for quiet or for disturbed days. Still less can we judge whether, if potentials apply in both cases, the ratio between the contributions from the external and internal fields will be the same for the two.

Finally, even if we knew that a potential gave the regular diurnal variation all over the earth on disturbed days, we should not be justified without further enquiry in assuming that the ratio between the external and internal fields deduced from it applied to disturbance as a whole.

It seems to me that the assumption

$$\delta_o \mathrm{H} = \delta_i \mathrm{H}$$

would be no more arbitrary, and even more simplifying, than the assumptions actually made by Dr. Chapman. At the present moment, and I suspect for some time to come, any positive disproof of such a hypothesis would be very difficult.

If we made this assumption, and accepted Dr. Chapman's mathematical formulæ, only the "self-energy" would survive in the energy integral, and

* 'Koninklijk Nederlandsch Meteorologisch Instituut,' No. 102 (specially p. 112).

† *Loc. cit.*, p. 14.

the final result would depend simply on $(\delta_0 H)^2 \times$ (volume between earth and external current sheet).

If we supposed the maximum mean hourly value from N, W and V combined at Eskdalemuir in Table VII to be the mean value for the space between the earth and a concentric surface at the supposed altitude, 100 kilom., of the overhead currents, we should obtain for the space integral of the "magnetic activity" throughout this volume $0{\cdot}4 \times 10^{20}$ ergs, the precise value obtained in Dr. Chapman's equation (20) for his "self-energy integral." This is, of course, a pure coincidence.

§ 8. The phenomena described in the present and my previous paper are not favourable to the view that any very simple general theory of magnetic storms is likely to add directly much to our knowledge. In the storms we have discussed the large increase in the disturbance as we travel the comparatively short distance from Kew to Eskdalemuir suggests a principal source much nearer than the pole of the zonal harmonic of the Gaussian potential, while the large difference between Kew and Agincourt is far from suggesting symmetry round the axis of the harmonic. Something may, I think, be learned from the consideration of auroral phenomena. Magnetic and auroral phenomena do not, it is true, show a strictly proportional development. Those who have compared magnetic records from high latitudes with aurora have found that times of brightest aurora and times of largest magnetic disturbance by no means always coincide. It has been inferred that bright aurora is dependent on the concentration of electric current at a height where the atmospheric conditions favour luminosity. These currents no doubt cause magnetic disturbance, but their influence may be less than that of other currents, whether at a lower altitude or more generally distributed. Still, when a large magnetic disturbance occurs, aurora generally proves to have accompanied it, and for aurora to be seen in southern England unaccompanied by a magnetic storm is almost, if not quite unprecedented. Whilst the well-known diagram of auroral frequency, due to Fritz, may well want revision in view of more recent knowledge, its main indications are presumably reliable. They indicate a zone of maximum frequency whose largest diameter is from 30° to 40°. When we superpose magnetic data from a large number of storms, commencing at all hours of the day, we may get phenomena roughly symmetrical round the centre of the auroral zone, but any such symmetry seems improbable on a given occasion. Aurora itself certainly shows no such symmetry. At a given instant it is usually concentrated in a particular part of the heavens, and in the northern hemisphere often extends much to the south of the auroral zone. Supposing magnetic disturbance mainly due to the concentration of electric currents in one definite region of

the auroral zone, it is the distance from that region, not from the centre of the zone, that is likely to be the all-important thing. It will make all the difference to a particular station whether the concentration of current is on the near or the remote side of the zone. From this point of view, the most promising way of extending our knowledge is to compare individual records from a series of stations lying roughly on a north-south line, and so not differing much in local time. A station in the extreme north of Scotland or in the Orkneys or Shetlands would seem likely to add much to our knowledge.

On the Inter-crystalline Fracture of Metals under Prolonged Application of Stress (Preliminary Paper).

By Walter Rosenhain, B.A., D.Sc., F.R.S., and Sydney L. Archbutt, F.I.C. (both of the National Physical Laboratory).

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[Plates 1–3.]

The authors have recently made a series of observations on some cases of inter-crystalline fracture in various metals, occurring as the result of the prolonged application of stress. In explanation of these phenomena they have formulated an hypothesis which appears to afford a satisfactory account of the present observations and to correlate them with other well-known phenomena whose exact nature has, however, hitherto remained obscure. In putting their observations and hypothesis on record at the present stage, the authors are well aware that much fuller experimental investigation of the whole subject is required, and they hope to carry this forward. The evidence now available, however, appears to them to justify preliminary publication, especially in view of the fundamental interest and great practical importance of the subject.

The present paper relates to a group of phenomena some of which have long been known, in the case of brass, as "season cracking." Brass articles which have been manufactured by a process of alternate cold-working and annealing—such, for instance, as cartridge-cases and other articles made by operations of cupping and drawing—sometimes exhibit a tendency, after a period which may vary from a few hours to several years, to undergo spontaneous cracking. The occurrence of this type of failure of brass has